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Optimal Design of Wetland Ecological Water in the Shuangtaizi Estuary, Panjin[1]

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Abstract

The protection and utilization of wetland have been more and more important. According to measured water levels, discharge and cross-sections of the Shuangtaizi River network, this paper builds a hydrodynamic model to simulate water and salt movement based on the Mike11. The model was calibrated and validated by measured water levels of July, 2009. A series of irrigation scheme for the reed field were designed according to the hydrological characteristics of the wetland. The results show that volume of water shortage is 65.1 million cubic meters in dry years, 4.2 million cubic meters in average years and 40.5 million cubic meters in wet years. With the expansion of water facilities, the water shortage reduced to 30.6 million cubic meters, 16.3 million cubic meters and 17.4 million cubic meters respectively in dry years, average years and wet years. In wet years and average years, salinity of tidal prism water can satisfy the requirements of irrigation. However, due to high tide salinity in dry years, irrigation can not be directly used for the reed field.

Keywords—tidal river network, reed wetlands, Shuangtaizi estuary, ecological water

1. Introduction

Optimal allocation of water resources is mainly to arrange distribution of water resources reasonably through some methods such as hydraulic regulation, in order to maximize utilization of water resources. Traditional model usually considered water supply and economic benefits for the target. Theoretical research method includes supply-decided model and demand-decided model. Since 1990, due to

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intensification of water pollution and shortage of water resources, traditional configuration model cannot meet the actual needs. Foreign Scholars began to focus water quality restriction, water resources economic benefits and sustainable utilization of water resources on the optimal allocation of water resources. For instance, Javaid A. established a linear programming model to optimize the utilization of different quality for different irrigation systems in some area of Pakistan; Lu X. F., Wang T.L., et al. (2008) designed water allocation model that considered self-purification capacity of wetlands and increased sewage treatment capacity gradually to improve the Shuangtaizi estuary wetland, in Panjin.

Formerly related research on water resources optimal allocation seldom combined water diversion with projects, which are independent and separate. In recent years some researchers arranged water allocation according to the theory of river eco-environmental water allocations. China also started a series of research combined with practice to improve ecological environment, such as water distribution of Heihe, water transfer of Tarim river of Xinjiang, water supplement of Zhalong wetland of Heilongjiang and ecological water supplement of Nan-Si Lake. Good results have been achieved for above projects. Based on Mike11 HD hydrodynamic module and AD module, this paper analyzes the effects of rubber dam on salinity and tidal prism of Raoyang River.

2 River network model

2.1 Brief introduction

MIKE 11 HD applied with the Saint Venant Equations:

$$\frac{\partial A}{\partial t}+\frac{\partial Q}{\partial x}=q \tag{1}$$

$$\frac{\partial Q}{\partial t}+\frac{\partial}{\partial x}\left(\frac{Q^2}{A}\right)+gA\frac{\partial h}{\partial x}+g\frac{Q|Q|}{C^2AR}=0 \tag{2}$$

Where Q is discharge (m³/s), A is flow area (m^2), q is lateral inflow (m³/s), h is stage above datum (m), C is Chezy resistance coefficient ($m^{0.5}$/s), R is hydraulic or resistance radius (m).
The one-dimensional (vertically and laterally integrated) equation for the conservation of mass of a substance in solution, i.e. the one-dimensional advection-dispersion equation reads [6]:

$$\frac{\partial AC}{\partial t}+\frac{\partial QC}{\partial x}-\frac{\partial}{\partial x}\left(AD\frac{\partial C}{\partial x}\right)=-AKC+C_2q \tag{3}$$

Where C is the concentration (mg/L), D is the dispersion coefficient (m/s), A is the cross-sectional area (m^2), K is the linear decay coefficient (1/d), C_2 is the source/sink concentration (mg/L), q is the lateral inflow (m³/s).

The adopted numerical scheme is a 6-point Abbott-scheme for the equations of continuity and momentum. A computational grid of alternating Q (discharge) and h (water level) points is used. The computational grid is automatically generated on the basis of the user requirements. Q-points are placed midway between neighboring h-points and at structures, while h-points are located at cross-sections, or at equidistant intervals in between if the distance between cross-sections is greater than maximum dx. Based on the calculation results of HD dynamic model, Mike11 AD model can calculate time and space distribution of salinity gradient utilizing convection diffusion equation. Therefore, AD can be used as a simple water quality model for analyzing the dispersion of salty.

2.2 Calibration and Validation

The river branch analyzed in this study, the Shuangtaizi River, flows down stream for a distance of about 62 km and finally drains into the Bay of Liaodong. The index map of Shuangtaizi delta showing the study area is presented in Fig.1.

The measured flow in regulating sluice of Shuangtaizi was used as specified flow boundary. The measured water level of Sandaogou monitoring point was used as specified water level boundary. The upstream of Raoyang River was set as closed boundary. Considering the stability of model calculation and time requirements of calculation, time step was set as 3 min, space step was set for 50 m to 200 m with a total of 82 water level points and 79 points flow points.

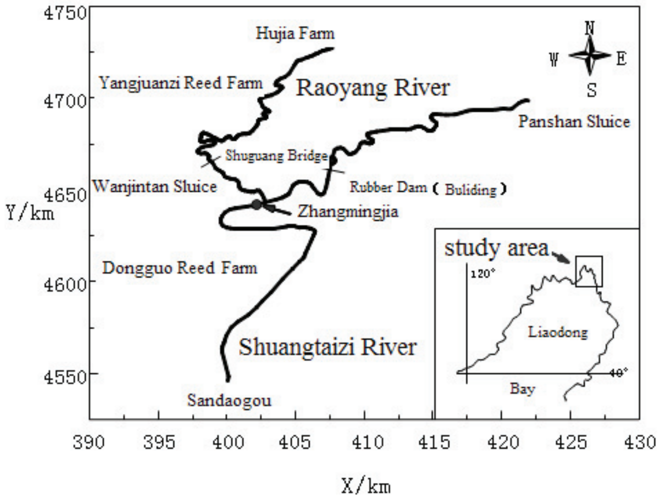

Fig.1 Map of Shuangtaizi delta showing Raoyang branch and gauging sites

The river channel roughness n was calibrated by measured water level from July 2, 2009 to July 7, 2009. Then measured water level from May 1, 2009 to May 10, 2009 and May 20 to 31 was used for validation. The results can be seen in fig 3-4.

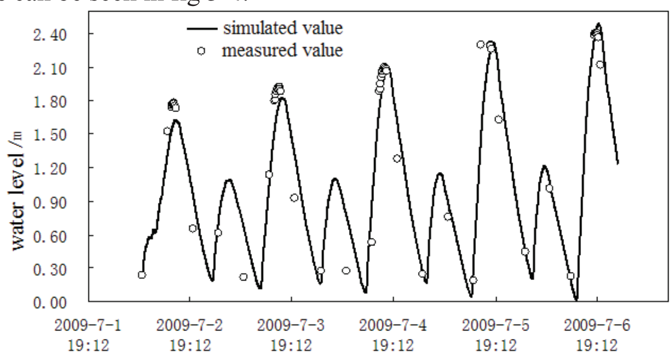

Fig. 2 Comparison of temporal variation of observed and predicted water levels at Zhangminjia gauging site

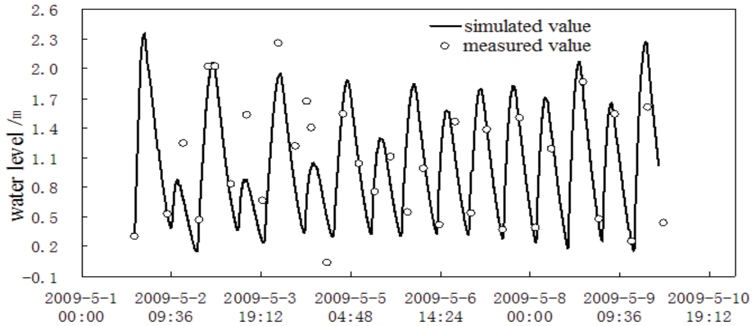

Fig. 3 Comparison of temporal variation of observed and predicted water levels at Zhangminjia gauging site in dry year with flow

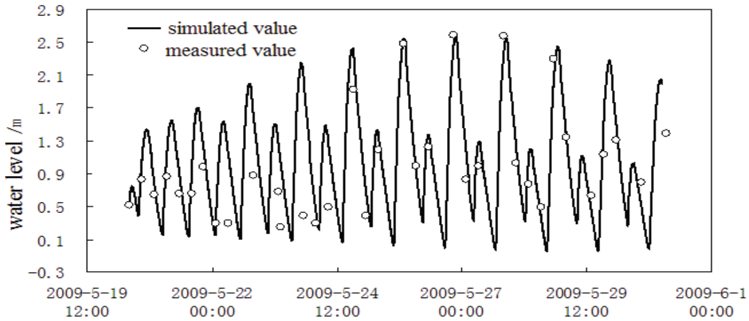

Fig. 4 Comparison of temporal variation of observed and predicted water levels at Zhangminjia gauging site in dry year with no flow

Based on the results of calibration and verification, calculated water levels and measured water levels coincided well and errors was within the acceptable limits. Roughness coefficient of Shuangtaizi river ranged from 0.008 to 0.03. Roughness coefficient of Raoyang river ranged from 0.01 to 0.02. It showed that roughness coefficient of the river matches physical truth well and the model can reflect resistance characteristics of riverbed.

Fig. 5 showed the validation results of longitudinal dispersion coefficient. We can see that calculated salinity and measured salinity coincided well, so longitudinal dispersion coefficient of the estuary channel accorded with spatial variation of salinity and can be used in the simulation of river salinity.

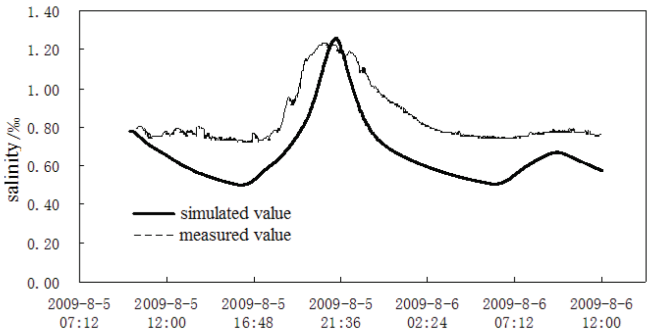

Fig. 5 Comparison of observed and predicted salinity at Zhangminjia gauging site

3. Regulation Design

(1) Dry, average, wet year: 1972 selected as dry year; 1994 selected as wet year; 2008 selected as average year.

(2) Irrigation time: According to practical experience of reed irrigation “three recharges and three drainages”, three time’s pumping time are not less than 9, 13 and 18 days, respectively. Corresponding pumping periods are set from March 20 to April 7, May 20 to June 14, and July 10 to 14, respectively.

Table 1 regulation of different operation schemes

Scheme		Year	Pumping Time	Pumpage (m^3/s)		
				Shengli	Shuguang	Hongqi
Regulation based on existing situation	A	A（1972）	3.20-3.29	21.6	0	0
		A（1994）				
		A（2008）	3.29-4.07	0	6	11.6
	B	B（1972）	5.20-6.02	21.6	0	0
		B（1994）				
		B（2008）	6.02-6.14	0	6	11.6
	C	C（1972）	7.10-7.28	21.6	0	0
		C（1994）				
		C（2008）	7.28-8.14	0	6	11.6
Regulation based on expanded Hydraulic Engineering	D	D（1972）	3.20-3.29	21.6	0	0
		D（1994）				
		D（2008）	3.29-4.07	0	9.6	18.7
	E	E（1972）	5.20-6.02	21.6	0	0
		E（1994）				
		E（2008）	6.02-6.14	0	9.6	18.7
	F	F（1972）	7.10-7.28	21.6	0	0
		F（1994）				
		F（2008）	7.28-8.14	0	9.6	18.7

Based on the above three consideration, 18 water diversion design scheme can be seen in table 1. Because of the limited storage of the channel water, Shenglitang pumping station operates independently. Hongqi and Shuguang pumping stations operate at the same time, their operations staggered to reduce the channel load.

4. Simulation of Diversion Scheme

Boundary condition: Three pumps are set as point source, minus represents carrying water out from river. In March, April every year, Shuangtiazi River ice melts and forms spring flood. This part of fresh water will be used for reed irrigation, entering Raoyang River through Shuangrao main canal. So this flow is positive.

Initial Conditions: Upstream and downstream water levels of Raoyang River are provided by measured data. Water level in other position can be reckoned through channel bed slope.

Salinity of the upstream of Shuangtaizi River is close to that offreshwater and set as a fixed value 0.28‰. Salinity of the upstream of Raoyang River is set as 0.6‰. Shuangtaizi River is affected by tidewater, so real-time measured value is utilized.

According to simulated pumping load and pumping time, we can calculate theoretical pumping load of the scheme. Theoretical pump of scenario A-F are 30.48 million m^3, 44.02 million m^3, 64.35million m^3, 38.8 million m^3, 56.04 million m^3 and 81.91 million m^3, respectively. But inflow and water level are different in the process of simulation, practical pump equals to theoretical value when water supply is adequate, otherwise we must calculate practical value through model correction value. On the basis of practical pumpage and water requirement of reed filed in table 1, volume of water shortage is calculated (table 2).

Table 2 operation results of regulations

Plan	Year	Theoretical Pumpage (m^3/s)	practical pumpage (m^3/s)	water Shortage (m^3/s)	water shortage (%)
A	A（1972）	3048	3027	1263	29.4
	A（1994）		2887	1403	32.7
	A（2008）		3048	1242	29.0
B	B（1972）	4402	3811	2624	40.8
	B（1994）		3793	2642	41.1
	B（2008）		4402	2033	31.6
C	C（1972）	6435	5959	2621	30.5
	C（1994）	no pumping in flood		0	0.0
	C（2008）	6435	6435	2145	25.0
D	D（1972）	3880	3712	578	13.5
	D（1994）		3771	519	12.1
	D（2008）		3880	410	9.6
E	E（1972）	5604	4946	1489	23.1
	E（1994）		5210	1225	19.0
	E（2008）		5604	831	12.9
F	F（1972）	8191	7588	992	11.6
	F（1994）	no pumping in flood		0	0.0
	F（2008）	8191	8191	389	4.5

Table 2 shows that irrigation guarantee rate of all plans can achieve 50% accordance with the existing water conservancy projects of water diversion. Water shortage degrees of first and second irrigation in dry year are higher. Because of inflow is few in wet year, water shortage degrees are above 30%, as to the third time irrigation the runoff is too large. We can stop pumping to avoid numerical oscillation. In average year, water supply is relatively abundant and water shortage degrees are about 30%. After increasing water pumpage, water deficit of dry year decreases somewhat, still higher than that of wet and average year. Water shortage degree of first half wet year reduces to 20% and that of first half average year reduces to 10%.

Table 2 also shows that water shortage degrees are highest in the second irrigation. The reason is that spring flood exists in the first irrigation and the third irrigation is in the flood season.

Changes of salinity of Wanjintan sluice in dry year are higher than average and wet year, which affects heavily to reed filed irrigation. However, in average and wet year, because of large precipitation and runoff, salinity of Wanjintan sluice is low. Therefore, in dry year, besides of mastering changes of salinity timely, treated industrial wastewater and domestic sewage can also used to relief water shortage of reed flied.

5. Conclusion

The model is calibrated and validated by measured water level data of July and May, 2009. According to the hydrological characteristics of the wetland, we design a series of irrigation scheme for the reed field, the volume of water and salinity data can be acquired through the simulation. The conclusions are followed:

According to current situation results of ecological water use, the volume of water shortage is 65.08 million m^3 in dry year, 4.2 million m^3 in average year and 40.45 million m^3 in wet year, respectively. With the expansion of water facilities, the water shortage reduced to 30.59 million m^3 in dry year, 16.3 million m^3 in average year, 17.44 million m^3 in wet year, respectively. In the wet year and average year, salinity of tidal prism water can satisfy the requirements of reed, but in dry year, water supply is too salty for the reed.

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